CLINICAL OUTCOMES AFTER LUMBAR DISCECTOMY FOR SCIATICA: THE EFFECTS OF FRAGMENT TYPE AND ANULAR COMPETENCE

BY EUGENE J. CARRAGEE, MD, MICHAEL Y. HAN, MD, PATRICK W. SUEN, MD, AND DAVID KIM, MD

Investigation performed at the Spinal Surgery Section, Department of Orthopaedic Surgery, Stanford University School of Medicine, Stanford, California

Background: The surgical treatment of sciatica with discectomy is ineffective in a sizable percentage of patients, and reherniation occurs after 5% to 15% of such procedures. The purpose of the present study was to determine if competence of the disc anulus and the type of herniation could be used to predict postoperative clinical outcomes following lumbar discectomy.

Methods: A prospective observational study of 187 consecutive patients undergoing single-level primary lumbar discectomy was conducted. A single surgeon performed all of the procedures, and an independent examiner evaluated 180 of the patients clinically at a minimum of two and a median of six years after surgery. The extent of anular deficiency and the presence of disc fragments were determined. On the basis of these intraoperative findings, disc herniations were classified into four categories: (1) Fragment-Fissure herniations (eighty-nine patients), (2) Fragment-Defect herniations (thirty-three patients), (3) Fragment-Contained herniations (forty-two patients), and (4) No Fragment-Contained herniations (sixteen patients). The effects of disc herniation morphology and preoperative variables on subsequent clinical outcome were determined with the Student t test for continuous variables and chi-square analysis for categorical variables.

Results: Patients in the Fragment-Fissure group, who had disc fragments and a small anular defect, had the best overall outcomes and the lowest rates of reherniation (1%) and reoperation (1%). Patients in the Fragment-Contained group had a 10% rate of reherniation and a 5% rate of reoperation. Patients in the Fragment-Defect group, who had extruded fragments and massive posterior anular loss, had a 27% rate of reherniation and a 21% rate of reoperation. Patients in the No Fragment-Contained group did poorly: 38% had recurrent or persistent sciatica, and the standard outcomes scores were less improved compared with those in the other groups ($p < 0.001$).

Conclusion: Intraoperative findings, as described in the present study, were more clearly associated with outcomes than were demographic, socioeconomic, or clinical variables. The degree of anular competence after discectomy and the type of herniation appear to have value for the prediction of the recurrence of sciatica, reoperation, and clinical outcome following lumbar discectomy.

Level of Evidence: Prognostic study, Level I-1 (prospective study). See p. 2 for complete description of levels of evidence.

Unsuccessful surgical treatment of sciatica due to herniated lumbar intervertebral discs is a major health-care problem. Previous studies have demonstrated that 20% to 40% of patients who have had an open discectomy for the treatment of a herniated lumbar intervertebral disc have had persistent or recurrent sciatica, intractable back pain, or recurrent disc herniations[1-9]. Investigators have focused on the type of decompression performed, patient selection, and accurate diagnosis in an effort to explain the so-called postlaminectomy syndrome[3-5,10-12]. Imaging studies have improved to the point that negative explorations are quite rare, and the clinical presentation of a patient with acute sciatica is usually straightforward. Yet, failures continue to occur with unacceptable frequency.

While some authors have claimed that the size of a disc herniation on magnetic resonance imaging or computerized tomographic scanning has no predictive value with regard to sci-

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EXHIBIT I **BEST AVAILABLE COPY**

, others[11] have reported very high success rates for pa-ts who have a large disc herniation that is excised by means . posterior discectomy. Studies evaluating the preoperative ;netic resonance images of patients with disc herniations ; indicated that the size and shape of the protrusion predict success of treatment more accurately than do clinical param-s such as Workers' Compensation status, age, and gender[3,15]. er studies have indicated that the integrity of the anulus may ssociated with the clinical outcome[5,16-18]. Yet, in most clinical :s, patients with "disc herniations" have generally been re-:ed as a single pathological group, hampering analyses be-:n subgroups and between studies.

An empirical classification system based on intraopera- findings (the type of disc herniation and the status of the :erior part of the anulus) was developed. In order to deter-e if there was a relationship between the preoperative ana-ical characteristics of the disc and outcome, we undertook ·ospective study in which the clinical, imaging, and de-d operative findings for each patient were evaluated with rd to the intermediate-term clinical outcome, the rate of rrent or persistent sciatica, and the rate of reoperation.

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ent Selection

he present study was approved by our Institutional Review Board, and all patients provided informed consent. The ɔpulation consisted of 187 consecutive patients with ica who were managed with limited posterior lumbar dis-ɔmy by a single surgeon (E.J.C.). To be included, a patient to have (1) a diagnosis of sciatica with predominantly :ular symptoms (that is, with lower extremity symptoms g greater than back or buttock symptoms), (2) a preopera- magnetic resonance imaging study confirming a disc her-on, and (3) an age of eighteen to sixty-five years. Patients excluded if they had (1) a history of a previous back oper-ı, (2) the inability to undergo full sequenced lumbar mag-: resonance imaging, (3) the need for an open scanner or netic resonance tomography, (4) a foraminal or extrafo-nal disc herniation, (5) a spinal malignancy, (6) a spinal ·tion, (7) an extraspinal cause of sciatica, or (8) neurogenic lication without a positive straight-leg-raising sign. Pa-s with notable nonintervertebral disc abnormalities such ondylolysis, spondylolisthesis, scoliosis, inflammatory ar-is, or metabolic bone disease were also excluded.

Surgery was offered if the patient had had a failure of six :s of nonoperative treatment, had intolerable sciatica, or ;evere neurological loss (motor loss or symptoms or signs uda equina syndrome). In addition, the symptoms had to tributable to a single intervertebral disc level and the pa- had to have agreed to participate in protocol follow-up ıinations.

The only surgical treatment offered to the surgical candi-.s a limited posterior discectomy. Therefore, the study ɔ represented a consecutive series of all subjects who met ıclusion criteria and who underwent surgery because of a herniation. Preoperative demographic data, clinical data, and quantitative data were collected for each patient. Quantitative data were collected with use of a pain drawing, two preoperative back-scoring instruments (the Oswestry Low Back Pain Disability Questionnaire[19] and a visual analog scale for the rating of back and leg pain), and two psychometric tests (the Modified Zung Depression Scale[12,20] and the Modified Somatic Perception Questionnaire[12,21]). Furthermore, occupational history, recreational history, Workers' Compensation status, other litigation claims, and previous nonoperative treatments were also documented for each patient.

One hundred and eighty (96%) of the 187 patients were available for follow-up after a minimum of two years (median, six years). There were more than twice as many men as women in the study group. Relatively few patients had filed a Workers' Compensation claim (19%) or a personal injury claim (6%).

Magnetic Resonance Imaging Analysis

Each scan was downloaded from an optical disc storage format and was examined on the independent console of a Signa 1.5-T imager (General Electric, Schenectady, New York). Axial images were magnified to improve visualization, and measurements were made with use of the trackball and cursor. Measurements were made on axial T2-weighted scans with a repetition time of 4000 msec and an echo time of 21 msec. The area of the disc, the area of the canal, the anteroposterior diameter of the disc, and the maximum right-left width of the disc on the axial image were then measured. The intraobserver and interobserver error associated with this method have been determined to be <3%[5].

Surgical Technique

All procedures were performed with the patient in the kneeling position with use of an Andrews Spinal Surgery Table (Orthopaedic Systems, Union City, California), and 136 procedures were performed with use of an operating microscope. All patients received a single dose of prophylactic antibiotics at the time of the incision. In some patients, the discectomy could be done through the interlaminar space alone. A small laminotomy was performed in the remaining patients. Medial facetectomy was performed rarely and only if the medial facet was clearly impinging on the nerve root after discectomy. The midline interspinous ligaments were preserved in all cases. No drains were used.

Operative Findings

Herniation type was determined on the basis of the operative findings. The anular defect was visualized, explored, and rated as a large defect, a small fissure, or an intact anulus. If a defect was found, the surgeon explored it further and determined if any free fragments were present. All fragments were then removed. The disc space was not curetted or débrided deep to the anulus except to remove loose fragments. If the apparent disc protrusion was covered with attenuated anular or areolar tissue, an attempt was made to broach the tissue with a number-4 Penfield probe (KMedic, Northvale, New Jersey). When this attempt was successful, a detached fragment was usually encountered deep to the membrane. When it was unsuccess-

TABLE I Disc Herniation Classification System

Disc Herniation Type	Presence of Extruded or Subanular Fragments	Anular Integrity	Surgical Treatment
Fragment-Fissure	Yes	Slit-like/small anular defect	Removal of fragments through slit-like anular defect
Fragment-Defect	Yes	Large/massive anular defect	Removal of fragments through massive anular defect
Fragment-Contained	Yes	No defect	Oblique incision in anulus performed to remove subanular fragments
No Fragment-Contained	No	No defect	Extensive anulotomy/removal of protruding disc

ful, an oblique 45° incision was made with a number-15 blade and the slit was explored. In some cases, a detached fragment was encountered. If no detached disc fragment was found, the bulging area beneath the traversing nerve root was removed piecemeal, creating a large iatrogenic anulotomy. The disc was then débrided back to the level of the posterior vertebral wall.

The anular defect after discectomy was compared with the width of a number-1 Penfield probe (6 mm). Defects that were wider than the probe were classified as large defects.

From these observations, four types of disc herniations were described: (1) Fragment-Fissure herniations (characterized by disc herniation with a minimal anular defect and an extruded or sequestrated fragment), (2) Fragment-Defect herniations (characterized by disc herniation with a large or massive anular defect and an extruded or sequestrated fragment), (3) Fragment-Contained herniations (characterized by disc herniation with an intact anulus and one or more subanular detached fragments that were removed by making an oblique incision in the anulus), and (4) No Fragment-Contained herniations (characterized by disc herniation with an intact anulus and no subanular detached fragment) (Table I). This last type of herniation was treated with an extensive anulotomy and piecemeal removal of the anular protrusion, leaving a large or massive anular defect.

Operative Findings and Observer Error

The discectomy procedure was videotaped through the operating microscope. The interobserver error was determined on the basis of the first thirty-two herniations that were classified by the surgeon. These videotapes were blindly reviewed by two independent examiners, and the fragment type and anular defect were classified as described above. Ninety-six ratings were done (including the intraoperative ratings done by the surgical team). The classifications made by the three readers were concordant in twenty-nine cases. The fragment type was rated concordantly in thirty (94%) of thirty-two cases, and the anular defect was rated concordantly in thirty-one (97%) of thirty-two cases.

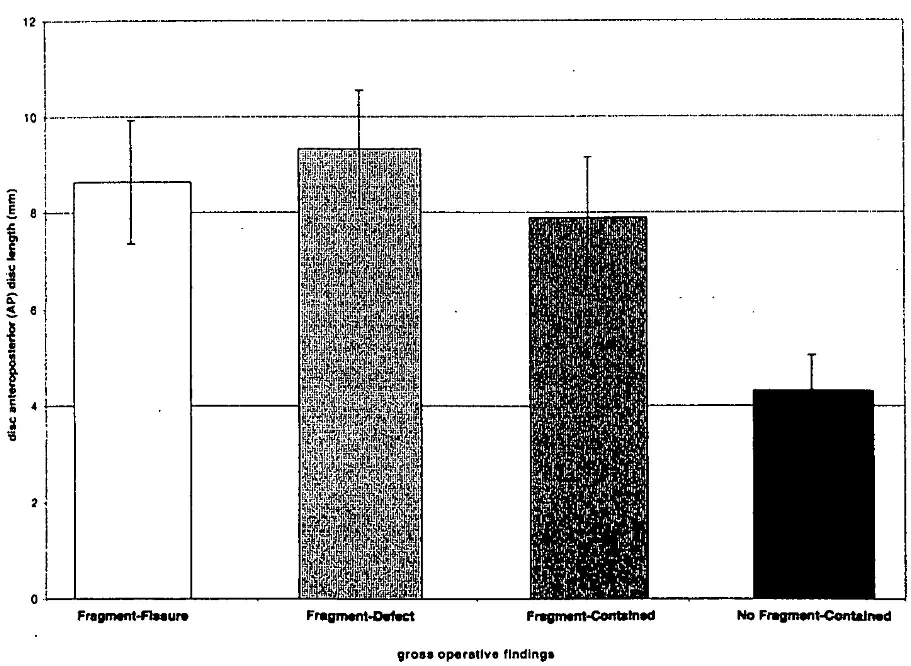

Fig. 1
Comparison of anteroposterior (AP) disc length on magnetic resonance imaging ($p < 0.0001$ for No Fragment-Contained disc herniations versus all other disc herniations, and $p < 0.005$ for Fragment-Contained disc herniations versus Fragment-Defect herniations).

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Outcome Measures

An independent examiner (D.K.) clinically evaluated the patients at a minimum of two years postoperatively. Patients filled out the postoperative back-scoring instruments (the Oswestry Low Back Pain Disability Questionnaire[19], a visual analog scale for back and leg pain, and a visual analog scale for activity and outcome satisfaction). The Stanford Score[3] was calculated on the basis of the four visual analog scores and medication usage. A Stanford Score of 10 points represented no back or leg pain, full activities, full satisfaction with the outcome, and no medication usage, whereas a score of 0 points indicated the worst imaginable back and leg pain, no activities, no satisfaction with the outcome, and daily narcotic medication. Any patient with recurrent sciatica underwent a magnetic resonance imaging evaluation. If an objective cause of the recurrent pain could be determined, the patient was offered a second operation.

Statistical Methods

Analyses of continuous variables were done with use of the unpaired Student t test. Chi-square and Fisher exact tests were used to compare categorical variables. Bonferroni-corrected p values were determined. Individual logistic regression analysis was performed on possible confounding variables, such as the duration of symptoms, the duration of work loss, age, operative time, intraoperative blood loss, the duration of hospitalization, work type, pending litigation, gender, and the presence of a Workers' Compensation claim, to determine the relationship of these variables with the outcome variables. Stepwise logistic regression analysis was also performed to determine the relationship of the above variables with the rates of reherniation and reoperation. Adjusted Kaplan-Meier survival curves were used to calculate reoperation and recurrence statistics. The statistical analysis was performed with use of the StatView program (Abacus Software, Mountain View, California).

Results

The most common herniation types in the present study were the Fragment-Fissure and Fragment-Contained herniations, which were found in 49% (eighty-nine) and 23% (forty-two) of the patients, respectively. Fragment-Defect herniations were found in 18% (thirty-three) of the patients, and No Fragment-Contained herniations were found in 9% (sixteen) of the patients.

When the symptoms and psychometric data that were associated with each disc herniation type were compared, we found significantly lower preoperative Oswestry Disability Questionnaire scores ($p = 0.01$) and a longer duration of preoperative work loss ($p < 0.001$) in the No Fragment-Contained herniation group (Table II). This group also tended to have more Workers' Compensation claim7s and a longer duration of symptoms prior to surgery. The No Fragment-Contained herniation group also had the smallest disc area ($p = 0.01$) and the smallest disc anteroposterior diameter ($p < 0.0001$) on magnetic resonance imaging (Table II and Fig. 1).

The patients in the Fragment-Contained and Fragment-Fissure groups had the best clinical outcomes as determined

TABLE II Preoperative Patient Characteristics and Outcome Assessments According to Fragment Type and Anular Defect

	All Patients	Fragment-Fissure Group	Fragment-Defect Group	Fragment-Contained Group	No Fragment-Contained Group
No. of patients	180	89	33	42	16
Age *(yr)*	37.5	37.8	37.0	38.7	31.7
Preoperative duration of symptoms* *(wk)*	17.0 (1-104)	16.1 (1-52)	20.0 (2-104)	15.1 (1-52)	21.1 (3-52)
Preoperative duration of work loss*† *(wk)*	3.7 (0-52)	3.8 (0-51)	3.1 (0-42)	2.5 (0-18)	8.0‡ (0-52)
No. of patients with Workers' Compensation claim	34 (19%)	16 (18%)	4 (12%)	9 (21%)	5 (31%)
Preoperative Oswestry Score* *(points)*	47.2 (18-88)	48.1 (21-81)	51.4 (14-88)	44.9 (31-74)	39.0§ (5-62)
Disc area on magnetic resonance imaging* *(mm²)*	128.5 (18-410)	130.5 (33-210)	142.2 (39-410)	126.7 (54-212)	93.5§ (18-157)
Anteroposterior diameter of disc protrusion* *(mm)*	8.2 (2-15)	8.7 (3-15)	8.8 (3-13)	8.3 (3-14)	4.3‡ (2-8)

*The data are given as the mean, with the range in parentheses. †The data on the duration of preoperative disability are given only for working patients. ‡$p < 0.001$. §$p = 0.05$ to 0.01.

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TABLE III Postoperative Patient Characteristics and Outcome Assessments According to Fragment Type and Anular Defect

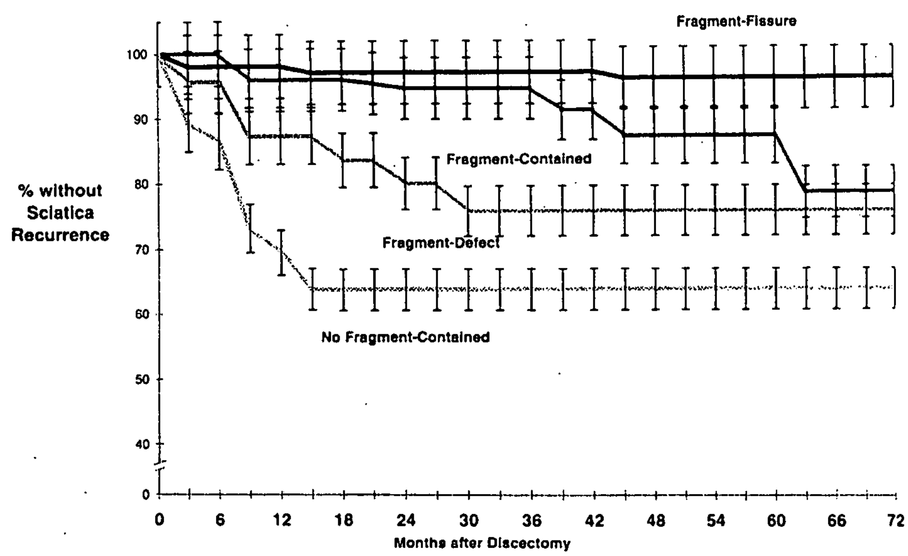
	All Patients	Fragment-Fissure Group	Fragment-Defect Group	Fragment-Contained Group	No Fragment-Contained Group
No. of patients	180	89	33	42	16
Duration of postoperative sick leave*† *(wk)*	1.2 (0-8)	1.2 (0-8)	1.3 (0-4)	1.0 (0-4)	1.7 (0-4)
Postoperative Oswestry score* *(points)*	12.7 (0-69)	11.6 (0-28)	16.4§ (2-48)	9.2 (0-19)	20.1# (0-69)
Stanford score* *(points)*	8.5 (2.8-10)	9.0§ (4.1-10)	8.0 (3.9-10)	8.8 (6.0-10)	6.0# (2.8-9.5)
Rate of recurrent/ persistent sciatica‡	11.7% (21)	1.1%** (1)	27.3% (9)	11.9% (5)	37.5%# (6)
Rate of documented reherniation‡	8.9% (16)	1.1%§ (1)	27.3%§ (9)	9.5% (4)	12.5% (2)
Rate of reoperation‡	6.1% (11)	1.1% (1)	21.2%# (7)	4.8% (2)	6.3% (1)

*The data are given as the mean, with the range in parentheses. †The duration of postoperative work loss is given only for patients who eventually returned to work. ‡The data are given as the percentage, with the number of patients in parentheses. §p = 0.05 to 0.01. #p < 0.001. **p = 0.009 to 0.001.

with the postoperative Oswestry and Stanford scores (Table III). Poorer scores were found in the Fragment-Defect ($p = 0.01$) and No Fragment-Contained groups ($p < 0.0001$). The patients in the No Fragment-Contained group had the highest rate of persistent and recurrent sciatica ($p < 0.001$) and the second highest rate of reoperation. However, only two patients with recurrent sciatica in that group had a clear new-fragment reherniation at the same level. In four other patients in that group, postoperative magnetic resonance imaging showed only a broad anular bulge. In three of these four patients, selective nerve root blocks did not provide consistent relief. The patients in the Fragment-Defect group, who had the largest anular defects, had the highest rates of reoperation due to recurrent herniation ($p < 0.0001$). All of these patients had a clearly documented reherniation of a fragment on the same side and at the same level. Although this group accounted for only 18% (thirty-three) of the patients in the study group, nine of the sixteen magnetic resonance imaging-confirmed reherniations and seven of the eleven reoperations in the present study occurred in these patients (Table III).

Although persistent or recurrent sciatica was seen in six of the sixteen patients in the No Fragment-Contained group, a second operation was offered to only two of these patients. Further surgery was not offered to the other four patients because a clear structural abnormality responsible for the continued symptoms could not be identified. One patient who

Fig. 2
Adjusted Kaplan-Meier plot of sciatica-free survival according to herniation type.



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derwent arthrodesis did not have substantial improvement. In contrast, primary reoperation (discectomy alone in five patients and arthrodesis in two) was successful in six of seven patients in the Fragment-Defect group.

Analyses of other variables (duration of symptoms, duration of work loss, age, operative time, intraoperative blood loss, duration of hospitalization, work type, pending litigation, and gender) with individual and stepwise logistic regression analysis demonstrated no significant relationship between any of those variables and outcomes on the basis of the numbers available. In contrast, disc herniation type had a consistently significant relationship with clinical outcomes (Appendix). Patients with a Workers' Compensation claim had poorer outcomes than those who did not (Stanford score, 8.0 versus 8.6 points; p = 0.03).

Complications

There were eighteen perioperative complications (Table IV) and sixteen documented reherniations. Kaplan-Meier analysis of the adjusted rates of recurrence of sciatica as a function of herniation type revealed the greatest rate of recurrence in the No Fragment-Contained group (Fig. 2).

Discussion

We systematically classified lumbar disc herniation types and residual anular defects to determine if these factors were independently predictive of clinical outcome following discectomy. Our results suggest that differences in outcomes and in recurrence and reoperation rates can be predicted on the basis of operative findings. Patients who had extruded disc herniations with largely intact anuli (Fragment-Fissure herniations) did exceptionally well, with only one recurrence after a mean of five years. In contrast, patients who had extruded fragments with large or massive anular defects (Fragment-Defect herniations) accounted for most of the clinically important reherniations and reoperations over time. This group also accounted for all of the patients with more than one disc reherniation, and the rate of reoperation in this group was 21%. Patients with disc fragments contained within an intact anulus (Fragment-Contained herniations) tended to do well, with a 12% rate of recurrent sciatica, although this rate was higher than that in the Fragment-Fissure group.

The treatment of anular prolapses with no discrete fragments (No Fragment-Contained herniations) by means of conventional anulotomy and limited discectomy was unsatisfactory. At one year after surgery, six of sixteen patients had notable recurrent sciatica. Most had no objectively identifiable reherniation, and aggressive nonoperative methods did not lead to improved outcomes. The Oswestry and Stanford scores reflected dramatically poorer functional, pain, and satisfaction ratings compared with those for all other treatment groups. Overall, this group had milder preoperative symptoms, a longer preoperative course, and a smaller herniation size on magnetic resonance imaging than other groups did. However, there were more compensation claims and psychometric abnormalities in this group. This small group of patients with sciatica appears to have a clinical profile resembling that of patients with chronic back pain who have attendant pain behavior and symptoms out of proportion with the pathoanatomical findings.

The possibility that these results may have been influenced by confounding factors was addressed with both individual and stepwise logistic regression analysis for a number of variables, including the duration of symptoms, the duration of work loss, age, operative time, intraoperative blood loss, the duration of hospitalization, work type, pending litigation, and gender. With the numbers available, none of these variables had a significant relationship with the rates of reherniation and reoperation. In contrast, disc herniation type had a significant association with the rates of reherniation and reoperation (p = 0.05 to 0.001). This finding strongly suggests that the disc herniation types described in the present study are independent predictors of clinical outcome.

The present study has inherent limitations. No control group was used. We believe that such a group is not practical in a study of disc herniation morphology. In addition, the selection of patients for surgery may not be generalizable to all spinal surgery practices. As all operations were done in a large university practice, the participation of residents and fellows and the practice biases of the referring doctors and the attending surgeon may have affected the selection of patients and may have biased the representation of the herniation types in our sample. Specifically, the proportion of patients with Workers' Compensation claims was very small. The psychometric scores recorded for these 180 patients were lower (less abnormal) than those reported for patients undergoing spine surgery in general[12]. Furthermore, the nature of a tertiary-care practice and the attending surgeon's usual practice of waiting at least six weeks before surgery may have lowered the proportion of extruded discs with massive anular defects in our series as many such patients may have had surgery acutely elsewhere.

The operation performed throughout this series was a modification of that described by Spengler et al.[8,22]: a magnification-assisted limited discectomy with little osseous decom-

TABLE IV Perioperative Complications

	No. of Patients
Dural tear	8
Transient footdrop	1
Prolonged wound drainage	1
Transient ulnar nerve weakness	1
Partial suprascapular nerve palsy	1
Superficial wound infection	1
Bilateral L5/S1 nerve palsy	1
Transient postoperative cauda equina syndrome	1
sient increased sciatica	1
Bladder retention requiring catheterization	2

pression and no attempt to remove anything other than loose fragments from within the intervertebral space. The outcomes recorded here are therefore specific to this procedure when performed at a training hospital. Whether these results can be generalized to other open or percutaneous techniques is unknown. The 96% rate of follow-up ensured little drop-out bias. Independent examiners using a protocol for final examinations also ensured uniform outcomes measures.

It appears that surgical findings may provide information about certain aspects of treatment and prognosis in a quantifiable manner. The limitations of conventional discectomy were demonstrated in patients with massive anular loss and those with anular prolapse without herniation of fragments.

The present study shows that certain subsets of herniated discs likely represent different clinical syndromes. The classification system described in this study may aid in the understanding and treatment of disc herniations. The identification of subgroups of disc herniations may allow investigators to better compare, communicate, and delineate the target populations for specific new techniques. We believe that the classification system used in this study has both treatment and prognostic implications.

Appendix

eA A table showing the effect of possible confounding variables on the rates of reherniation and reoperation as determined with logistic regression analysis is available with the electronic versions of this article, on our web site at www.jbjs.org (go to the article citation and click on "Supplementary Material") and on our quarterly CD-ROM (call our subscription department, at 781-449-9780, to order the CD-ROM). ■

Eugene J. Carragee, MD
Michael Y. Han, MD
Patrick W. Suen, MD
David Kim, MD
Spinal Surgery Section, Department of Orthopaedic Surgery, R171 Stanford University School of Medicine, Stanford, CA 94305

The authors did not receive grants or outside funding in support of their research or preparation of this manuscript. They did not receive payments or other benefits or a commitment or agreement to provide such benefits from a commercial entity. No commercial entity paid or directed, or agreed to pay or direct, any benefits to any research fund, foundation, educational institution, or other charitable or nonprofit organization with which the authors are affiliated or associated.

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